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Quantitative bedrock geology of the continents and large-scale drainage regions

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[1] We quantitatively analyze the area-age distribution of sedimentary, extrusive volcanic, and endogenous (plutonic and/or metamorphic) bedrock on the basis of data from the most recent digital Geological Map of the World at a scale of 1:25,000,000. The spatial resolution of the digital bedrock data averages 13,905 km^2 per polygon. Comparison of certain regions of the world, previously analyzed at higher spatial resolution, with the low-resolution world data reveals general consistency in the areal exposure of major rock types as well as a minor systematic bias toward older average bedrock ages in the global data set. Application of the global bedrock data to 19 large-scale drainage regions and three large, internally drained regions reveals considerable regional variability of Earth's bedrock geology that is consistent with the dominant geotectonic setting of the respective drainage region.

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1. Introduction

[2] We are extending our previous characterizations of bedrock composition in the conterminous United States of America [*Peucker-Ehrenbrink and Miller*, 2002], Alaska and Canada [*Peucker-Ehrenbrink and Miller*, 2003], East and Southeast Asia [*Peucker-Ehrenbrink and Miller*, 2003] and Brazil [*Peucker-Ehrenbrink and Miller*, 2007] to the entire world land surface in an attempt to improve global estimates of the lithologic composition and age distribution of bedrock using modern geographic information systems and digital geologic maps. We also use the delineation of 19 large-scale drainage regions [*Graham et al.*, 1999] to compute the lithologic variability of bedrock draining into regions of the world's oceans. This constitutes an intermediate step toward our ultimate goal of quantifying bedrock geology of major river basins in order to investigate the relationship between bedrock composition/age and the chemical composition of continental runoff. Neither the

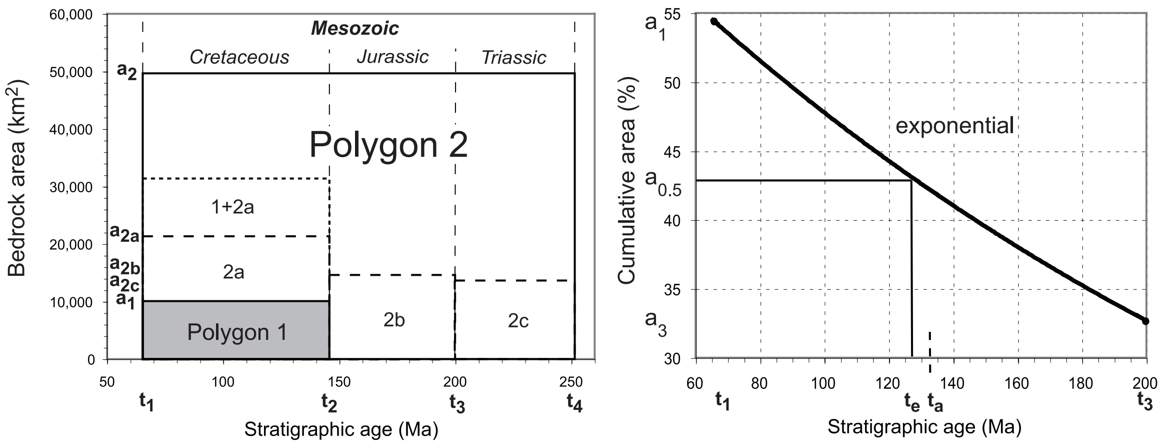

Figure 1. (left) Age model assuming uniform age-area distribution for each lithologic unit. (right) Age model assuming an exponential age-area distribution for each lithologic unit. See text for explanation.

lithologic-paleogeographic maps compiled by Ronov and coworkers at fairly coarse spatial resolution [e.g., *Ronov*, 1989] (and literature cited by *Peucker-Ehrenbrink and Miller* [2003]) nor the earlier global data by *Blatt and Jones* [1975] provide sufficient details for investigating individual river drainage basins. In addition, the *Ronov* [1989] data do not yet provide coverage for the Quaternary. They do, however, provide the only available global estimate of temporal changes in the geological makeup of the continents throughout the Phanerozoic, as quantified by *Bluth and Kump* [1991]. The recently published estimates of the lithologic makeup of large river basins [*Amiotte Suchet et al.*, 2003] do not include bedrock ages, and are thus not useful for investigating the effects of bedrock geology on the radiogenic isotope composition of continental runoff.

2. Data

[3] The *Commission for the Geological Map of the World* (*CGMW*) [2000] has made the Geologic Map of the World available in digital format at a scale of 1:25,000,000. The electronic directory of the commercially available CD contains the following seven ArcInfo (E00) files: geological units, geological contours, structural features, topography, hydrography, volcanism and astroblems, and grids.

[4] The *Graham et al.* [1999, 2000] data provide 5-minute (2160 × 4320 grid units), $\frac{1}{2}°$ (360 × 720 grid units), and 1° (180 × 360 grid units) delineations of large-scale drainage basins as Cartesian Geodetic grids, derived from a 5-minute global digital terrain model [*Row et al.*, 1995] and additional information from the CIA World Data Bank II [*Gorny and Carter*, 1987]. We have used the 5-minute grid unit data in combination with the global bedrock map to compute bedrock composition of 19 large-scale drainage regions into the oceans as well as large-scale internally drained (endorheic) regions (http://www.ngdc.noaa.gov/seg/cdroms/graham).

3. Methods

[5] The methods used are very similar to those employed in our previous studies [*Peucker-Ehrenbrink and Miller*, 2002, 2003, 2004, 2007]. Relevant projection parameters and software used are summarized in auxiliary material[1] Text S1.

[6] Ages (t) of lithologic units are defined by upper (i.e., younger) and lower (i.e., older) age boundaries. The difference between these age boundaries increases with decreasing map resolution and, generally, with the absolute age of lithologic units. In this study the average age of an individual lithologic unit (e.g., polygon 1, Figure 1 left) was calculated as the average between the upper (t_1) and the lower (t_2) age limit [$t_{polygon1} = (t_1 + t_2)/2$). Polygon areas (a) of lithologic units that span more than one subunit (e.g., polygon 2) were divided among the subunits (polygons 2a, 2b, 2c) according to the duration of each subunit relative to the main unit (e.g., $a_{2a} = a_2*(t_2 - t_1)/(t_4 - t_1)$). This is equivalent to assuming uniform survival probabilities for, for instance, Triassic, Jurassic and Cretaceous rocks. Average ages of regions that are composed of multiple polygons made up of differ-

[1] Auxiliary material data sets are available at ftp://ftp.agu.org/apend/gc/2006gc001544. Other auxiliary material files are in the HTML.

Table 1. Global and Regional Bedrock Geology

	Detail[a] % Area[c]	World[b] % Area[c]	Detail[a] Age, Myr	World[b] Age,[d] Myr	World[b] Area, km^2	World[b] Polygons[e]	Reference and Comments
Cont. U.S.							*Peucker-Ehrenbrink and Miller* [2002]
Sediments	81.7	79.8	210	285	6,181,803	649	Detail: Marine + Continental Seds.
Volcanics	8.9	13.3	223	339	1,030,145	62	-
Endogenous	9.2	6.9	1051	847	537,173	61	Detail: Pluton. + Metam. + Ultramafic
Alaska							*Peucker-Ehrenbrink and Miller* [2003]
Sediments	72.9	71.2	195	163	1,033,710	2,925	Detail: Marine + Continental Seds.
Volcanics	11.6	15.4	126	165	223,456	1,148	-
Endogenous	10.2	13.4	237	1020	194,427	1,162	Detail: Pluton. + Metam. + Ultramafic
Canada							*Peucker-Ehrenbrink and Miller* [2003]
Sediments	53.4	53.9	555	628	5,208,050	1,104	Detail: Marine + Continental Seds.
Volcanics	6	8.6	1377	1460	833,903	381	-
Endogenous	40	37.5	2281	2363	3,623,458	932	Detail: Pluton. + Metam. + Ultramafic
SE Asia							*Peucker-Ehrenbrink and Miller* [2004]
Sediments	73.2	74.3	123	219	7,036,054	975	Detail: Marine + Continental Seds.
Volcanics	8.5	12.7	84	77	1,205,149	244	-
Endogenous	17.4	12.9	862	887	1,222,501	303	Detail: Pluton. + Metam. + Ultramafic
World							*This study*
Sediments		69.9		246 ± 42	93,759,664	5,598	-
Volcanics		8.7		331 ± 52	11,724,992	1,813	-
Endogenous		21.4		1745 ± 269	28,687,027	2,989	-
All		100.0		574 ± 69	134,124,266	10,371	All bedrock units

[a] "Detail" refers to analysis of more detailed bedrock maps, previously analyzed in the publications listed in the References column.
[b] "World" refers to this study, bedrock map of the world at a scale of 1:25,000,000.
[c] To eliminate the effects of land area covered by glaciers (up to 2.6% of Alaska) and lakes (up to 1.2% in Canada), area percentages are normalized to 100% bedrock.
[d] Uncertainties are one standard deviation.
[e] Number of polygons.

ent lithologic units (e.g., Cretaceous = polygon 1 + polygon 2a) were then calculated by multiplying the age of each lithologic unit weighted by the area each unit covers ($t_{Cretaceous} = (t_{polygon1}*a_1 + t_{polygon2a}*a_{2a})/(a_1 + a_{2a})$). The half-area age is the age at which the area covered by younger bedrock equals the area covered by older bedrock. Uncertainties were computed using a Monte Carlo method with uniform age probabilities between the lower and upper age limits. This method has a tendency to overestimate ages because of the decreasing survival probability of bedrock units with time [*Gregor*, 1968; *Gilluly*, 1969; *Garrels and Mackenzie*, 1971]. The degree to which ages are overestimated increases with the difference between lower and upper age limits. Overestimation is most significant for Precambrian units and, in general, for bedrock maps with low temporal (and spatial) resolution. Ages of Archean units are also influenced by the choice of the lower age limit that is usually not specified. For instance, changing the lower age limit from 3600 to 3900 Ma leads to an increase in the average age of Archean units by 150 Myr. At the end of section 4 we investigate quantitatively by how much average ages change if an exponential age model is used.

4. World Bedrock: Results and Discussion

[7] The results of our global analysis are summarized in Table 1 (complete data are in auxiliary material Table S1). Abbreviated rock descriptions, number of polygons per lithologic unit, and the respective bedrock area are listed in auxiliary material Table S1. The data cover an area of 509,130,478 km^2 with 14,900 polygons, 10,342 (134,076,849 km^2) of which cover continental bedrock that has been stratigraphically or radiometrically dated. The remaining polygons make up endogenous rocks of unknown age (29 polygons covering 47,417 km^2), offshore continental and island arc margins (299 polygons, 56,866,291 km^2), seamounts, oceanic plateaus and anomalous oceanic crust (1272 polygons, 21,866,792 km^2), oceanic crust (1656 polygons, 280,670,258 km^2), glaciers (94 polygons, 14,019,091 km^2), lakes (229 polygons, 911,513 km^2) and unidentified areas (979 polygons, 624,849 km^2).

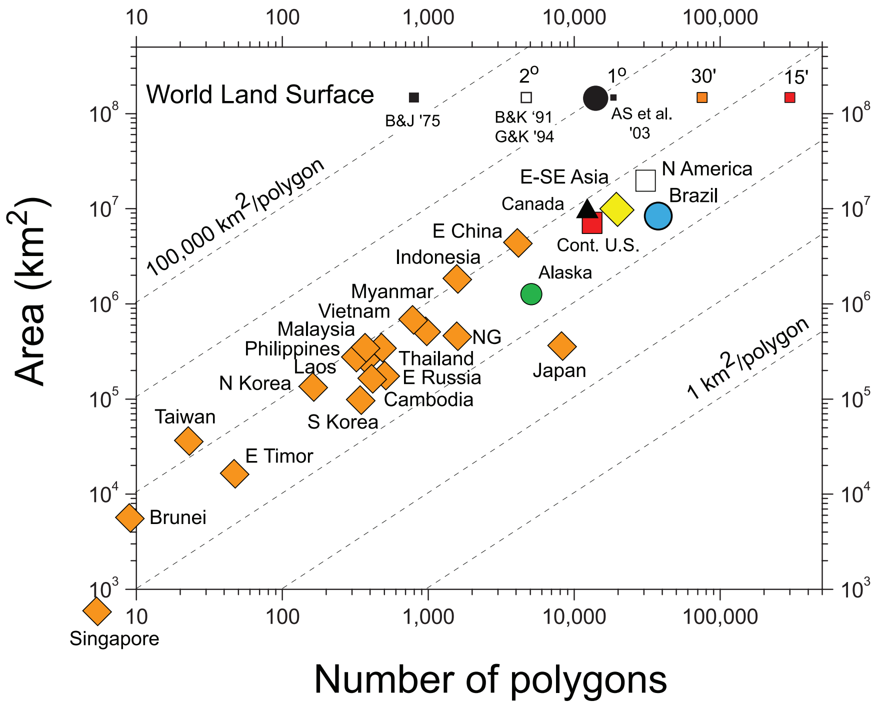

Figure 2. Spatial resolution (average area of a polygon in km^2) of digital bedrock maps for the world (large black circle), East and Southeast Asia (yellow diamond) as well as 18 countries in East and Southeast Asia (orange diamonds), Canada (black triangle), Alaska (green circle), the conterminous United States of America (red square), North America without Mexico (open white square), and Brazil (blue circle). Dotted lines are lines of equal spatial resolution. Characteristic resolutions of other global assessments of bedrock geology are shown as small squares. These range from coarse resolution of work by *Blatt and Jones* [1975] (BJ'75) that is equivalent to a resolution of >100,000 km^2 per polygon, to the work by *Bluth and Kump* [1991] (B&K'91) and *Gibbs and Kump* [1994] (G&K'94) at 2° spatial resolution, to the most recent assessment by *Amiotte Suchet et al.* [2003] (AS et al.'03) with a resolution of slightly better than 10,000 km^2 per polygon.

[8] Lithostratigraphic units are divided into three major groups: Sedimentary rocks (or undifferentiated facies), extrusive volcanic rocks, and endogenous (i.e., plutonic and metamorphic) rocks. These major groups are subdivided into 11 (sedimentary rocks), 11 (volcanic rocks), and 13 (endogenous rocks) stratigraphic sub-units. The number of polygons per stratigraphic sub-unit within each lithologic group ranges from a low value of just two polygons (undifferentiated Proterozoic and Paleozoic extrusive volcanic rocks) to 1135 polygons of Cenozoic extrusive rocks. Sedimentary rocks cover 93,759,664 km^2, or 62.9%, of the total land surface (69.9% of the bedrock area). Extrusive volcanic rocks cover 11,724,992 km^2, or 7.9%, of the entire land area (8.7% of the bedrock area), whereas endogenous rocks cover 28,687,027 km^2, equivalent to 19.2% of the total land area (21.4% of the bedrock area). This compares reasonably well with an earlier estimate by *Blatt and Jones* [1975] that determined the relative global exposure of sedimentary (66%), extrusive (8%) and endogenous bedrock (26%, i.e., 9% intrusive plus 17% metamorphic and "Precambrian" rocks). *Blatt and Jones* [1975, Table 3] based their analysis on 783 randomly chosen bedrock locations worldwide, a much lower spatial resolution than our present analysis (see Figure 2). Our data indicate slightly greater exposure of sedimentary rocks (70% versus 66%) and less exposure of endogenous rocks (21.4% versus 26%). Classifying *Blatt and Jones*'s [1975] "Precambrian" rocks entirely as endogenous bedrock rather than partly as sedimentary bedrock may contribute to this discrepancy. For instance, *Blatt and Jones* [1975] indicate that geologists classify ~5% of Precambrian rocks as sedimentary. Given these uncertainties, both estimates are essentially identical.

[9] Further sub-classification of these major lithologic units into marine and continental sediments, mafic and felsic volcanic, as well as plutonic and metamorphic rocks, as done in previous studies using higher-resolution digital bedrock maps, is not possible with this low-resolution global data set. However, comparison with previously published

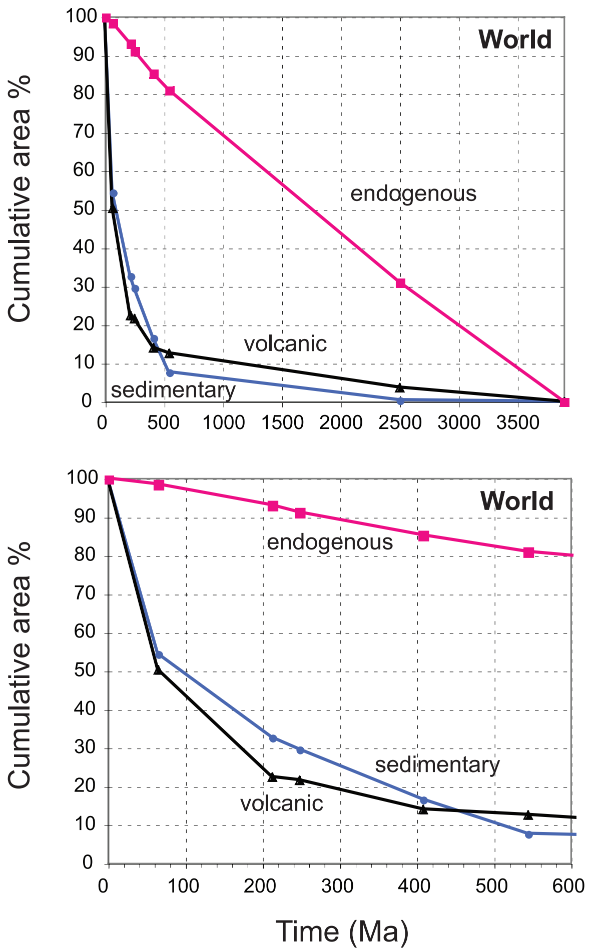

Figure 3. Global cumulative area-age distributions of sedimentary (blue circles), volcanic (black triangles), and endogenous (plutonic and metamorphic) (red squares) bedrock, from (top) 0 Ma to 3900 Ma and (bottom) 0 Ma to 600 Ma.

estimates of the global abundance of sedimentary and volcanic rocks reveals good overall agreement [*Clarke*, 1911; *Holmes*, 1913; *Khain and Ronov*, 1960]. This confirms a conclusion drawn by *Blatt and Jones* [1975, Table 2] that differences in map resolution (1:250,000-1:5,000,000) had little effect on estimates of relative distribution of rock types exposed in the U.S.

[10] The spatial resolution of the data varies from 6467 km^2 per polygon for volcanic rocks, 9597 km^2 per polygon for endogenous rocks, to 16,775 km^2 per polygon for sedimentary rocks. On average, the spatial resolution of dated bedrock is 12,964 km^2 per polygon (Figure 2). This resolution is comparable to a $\sim$1° gridded map [e.g., *Amiotte Suchet et al.*, 2003]. It is more detailed than the global compilation at a 2° scale by *Bluth and Kump* [1991] and *Gibbs and Kump* [1994], which are based on paleogeologic reconstructions by Ronov and coworkers [e.g., *Ronov*, 1989], and much more detailed than the low-resolution data of *Blatt and Jones* [1975].

[11] We use data for sedimentary bedrock (5598 polygons), volcanic rocks (1813 polygons), and endogenous rocks (2989 polygons) to compute normalized cumulative surface area for each time period mapped (Figure 3). Area values of undifferentiated units such as "Paleozoic to Mesozoic" were divided according to duration (km^2 Myr^{-1}) among the subunits. The *Harland et al.* [1990] (Cambrian-Precambrian boundary modified to 544 Ma) and *Lumbers and Card* [1991] timescales were used to define upper and lower age limits of each unit. It should be noted that at the given temporal resolution of the data, the choice of timescale is of minor importance to the data quality. The coarser temporal resolution of the global data implies a larger uncertainty in the calculated area-age relationships compared to previously analyzed data [*Peucker-Ehrenbrink and Miller*, 2002, 2003, 2004, 2007]. As we assign average ages of lithologic units based on the midpoint between the upper and lower age boundaries, a coarser temporal resolution tends to overestimate average ages compared to bedrock data with higher temporal resolution. This is caused by the fact that the survival probability of older bedrock decreases exponentially due to the combined effects of erosion (e.g., cannibalistic recycling of sedimentary rocks) and burial [e.g., *Gregor*, 1968, 1970, 1985; *Garrels and Mackenzie*, 1969; *Gilluly*, 1969; *Blatt and Jones*, 1975]. We argue that this explains the offset to older average ages of some major lithologic units in the global data set compared with regional, higher-resolution data sets (see Table 2 and Figures 4 and 5).

[12] In order to investigate the severity of the age bias we have evaluated a different age model that takes the decreasing survival probability of older strata into account (*Gregor* [1968]; *Gilluly* [1969], *Garrels and Mackenzie* [1971]). Rather than using the average between upper and lower age limits ($t_a = t_1 + [t_3 - t_1]2$, Figure 1 right) we use an exponentially decreasing survival probability from the upper to lower age limit (Figure 1 right). The end-points of exponential line segments in plots of age versus cumulative area are defined by the upper (t_1 in Figure 1 right) and lower (t_3 in Figure 1 right) age limits (abscissa) and the relative cumulative area coverage at these age limits (a_1 and a_3 in Figure 1 right, respectively). The average age of a unit is defined as the age (t_e) at which, given an

Table 2 (Representative Sample). Bedrock Lithology and Age Structure of Large-Scale Drainage Basins and Internally Drained Basins[a] [The full Table 2 is available in the HTML version of this article at http://www.g-cubed.org]

Grid Code	Name	Total, km^2	Land, km^2	Lake/Ice, km^2	Ocean, km^2	Land, %	Lake/Ice, %	Ocean, %	Sediment, km^2	Extrusive, km^2	Endog., km^2	Sediment, % oL	Extrusive, % oL
1	Russian Arctic	20,442,658	13,087,208	118,636	7,236,814	64.0	0.6	35.4	10,512,695	904,748	1,669,764	80.3	6.9
2	N. American Arctic	8,845,768	3,577,966	796,760	4,471,042	40.4	9.0	50.5	2,857,204	132,178	588,585	79.9	3.7
3	E coast N. America	24,403,249	9,325,220	1,274,069	13,803,959	38.2	5.2	56.6	6,808,633	763,037	1,753,550	73.0	8.2
4	W. Europe	11,196,403	1,998,839	9,643	9,187,920	17.9	0.1	82.1	1,298,568	122,759	577,512	65.0	6.1
5	E coast S. America	44,976,066	16,562,670	57,219	28,356,178	36.8	0.1	63.0	10,987,851	1,567,864	4,006,955	66.3	9.5
6	West Africa	48,517,236	16,203,702	143,812	32,169,722	33.4	0.3	66.3	10,351,413	284,737	5,567,552	63.9	1.8
7	East Africa	37,377,060	6,423,185	47,568	30,906,307	17.2	0.1	82.7	3,647,743	617,406	2,158,036	56.8	9.6
8	Arabia-India-SE Asia	33,059,396	10,923,394	11,559	22,124,442	33.0	0.0	66.9	7,564,158	1,034,695	2,324,541	69.2	9.5
9	East Asia	74,099,636	14,073,715	19,765	60,006,155	19.0	0.0	81.0	10,179,443	2,002,634	1,891,638	72.3	14.2
10	W coast N. America	35,783,583	5,405,659	51,988	30,325,936	15.1	0.1	84.7	2,560,623	1,891,208	953,828	47.4	35.0
11	W coast S. America	67,513,707	1,220,853	17,667	66,275,187	1.8	0.0	98.2	464,297	455,409	301,146	38.0	37.3
12	Australia-NZ	38,767,848	7,967,110	24,125	30,776,613	20.6	0.1	79.4	6,333,393	403,323	1,230,394	79.5	5.1
13	Antarctica	34,228,858	1,523,722	12,450,843	20,254,293	4.5	36.4	59.2	441,610	345,304	736,808	29.0	22.7
14	Mediterranean	10,769,612	8,197,989	37,460	2,534,163	76.1	0.3	23.5	6,385,259	373,093	1,439,637	77.9	4.6
15	Kaspian-Aral Seas	8,561,700	8,049,943	114,600	397,156	94.0	1.3	4.6	7,509,604	150,829	389,510	93.3	1.9
16	Black Sea	2,925,756	2,453,129	9,026	463,601	83.8	0.3	15.8	2,070,638	111,867	270,623	84.4	4.6
17	Red Sea	1,398,537	935,189	2	463,345	66.9	0.0	33.1	218,625	288,931	427,633	23.4	30.9
18	Baltic Sea	2,274,503	1,846,881	32,782	394,840	81.2	1.4	17.4	1,080,065		766,816	58.5	0.0
19	Hudson Bay	4,934,099	3,753,826	38,504	1,141,769	76.1	0.8	23.1	1,751,394	303,572	1,698,860	46.7	8.1
Sum		510,075,675	133,530,201	15,256,029	361,289,444	26.2	3.0	70.8	93,023,217	11,753,594	28,753,390	69.7	8.8
World sum													
	Land		148,786,230		min	1.8	0.0	4.6			min	23.4	0.0
	Sea		361,289,444		max	94.0	36.4	98.2			max	93.3	37.3
	Total		510,075,675						133,530,201		median	66.3	8.1
1	North Africa - int.	7,436,540	7,413,017	23,523					6,112,057	132,527	1,168,433	82.5	1.8
2	Central Asia - int.	9,894,880	9,383,124	114,601	397,156				8,523,321	319,456	540,347	90.8	3.4
3	Central Australia - int.	3,288,044	3,265,271	22,773					2,785,946	74,791	404,534	85.3	2.3
Internal drainage		20,619,464	20,061,411	160,897	397,156	97.3	0.8	1.9	17,421,324	526,774	2,113,313	86.8	2.6

[a] Abbreviations: Endog., endogenous bedrock; % oL. percent of land area; ±Myr, age uncertainty (1 standard deviation); int., internally drained.

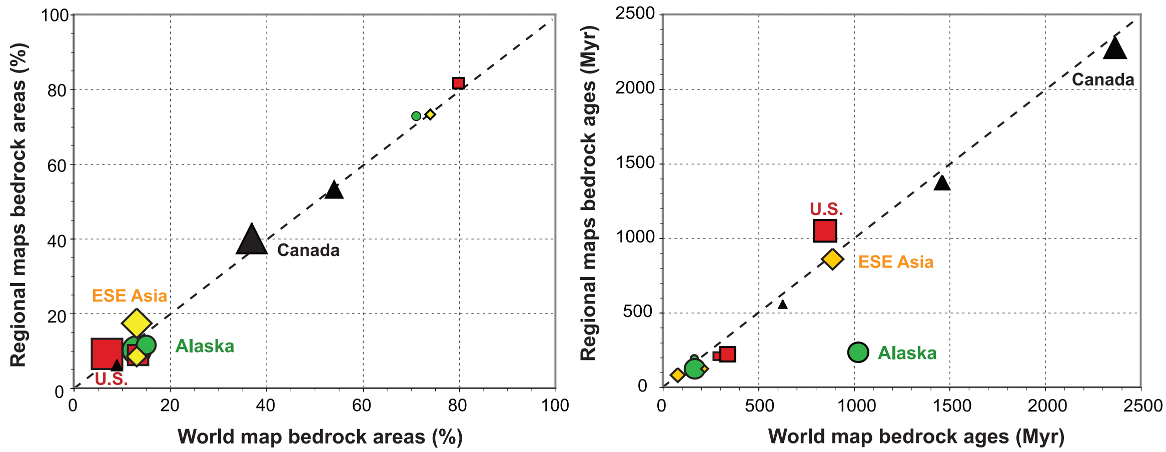

Figure 4. Comparison of global bedrock data with data computed from regional maps of higher spatial and temporal resolution. (left) Relative abundances (%) of sedimentary (small symbols), volcanic (medium-size symbols), and endogenous (large symbols) bedrock. (right) Average bedrock ages, weighted according to bedrock area assuming a uniform age distribution. Data for the conterminous U.S. are shown as red squares [*Peucker-Ehrenbrink and Miller*, 2002], green circles denote Alaska [*Peucker-Ehrenbrink and Miller*, 2002], black triangles symbolize Canada [*Peucker-Ehrenbrink and Miller*, 2003], and yellow diamonds represent data for east and Southeast Asia [*Peucker-Ehrenbrink and Miller*, 2004]. The hatched diagonal line indicates perfect agreement between estimates based on global data and those of regional data. While the agreement is generally good, there are notable exceptions (e.g., average age of endogenous rocks in Alaska is much older based on global data than on the higher-resolution regional data). Regional estimates of endogenous bedrock have been computed as the sum of igneous, ultramafic, and metamorphic bedrock. Regional estimates for sedimentary rocks have been computed as the sum of terrestrial and marine sedimentary rocks.

exponential survival probability, the area covered by younger strata equals the area that is covered by older strata ($a_{0.5} = a_3 + [a_1 - a_3]/2$). This age model shifts average bedrock ages to younger ages compared to a uniform survival probability within each unit (t_a in Figure 1 right). A comparison of the uniform and exponential survival probability models yields the following results for the 1:25,000,000 global bedrock map (CGMW, 2000): The average global bedrock age decreases from 574 Myr (uniform probability) to 459 Myr (exponential probability), whereas the average age of sedimentary

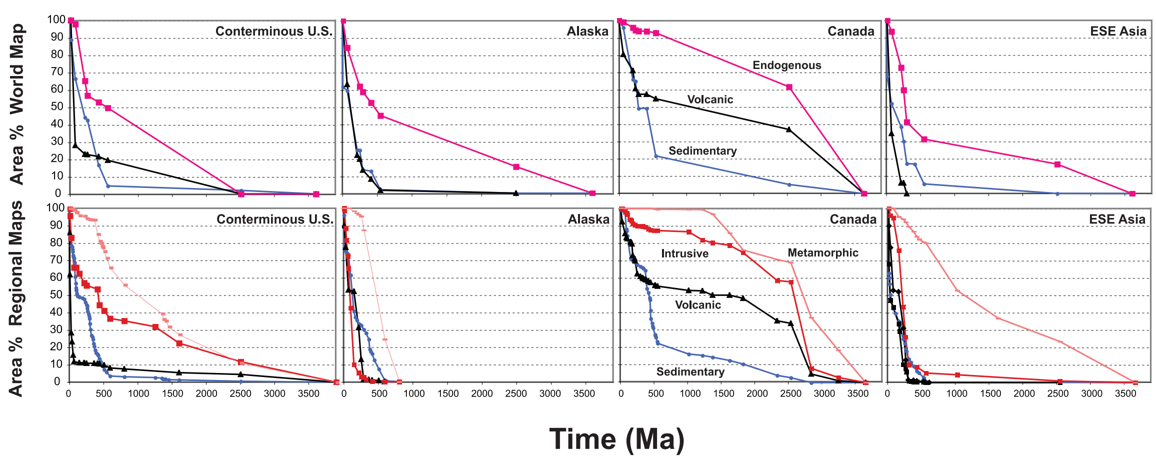

Figure 5. The figure shows area-age curves of sedimentary (blue circles), volcanic (black triangles), intrusive (red squares), metamorphic (pink rectangles), and endogenous (magenta squares, world map only) bedrock. The top panels show data for the conterminous U.S., Alaska, Canada, and east and Southeast Asia that are computed from the 1:25,000,000 global bedrock map. Data in the bottom panels are computed for the same regions using higher-resolution regional bedrock maps. Cumulative area percentages versus time are plotted. Area-age curves of endogenous bedrock (top panels) are roughly equivalent to the weighted sum of area-age curves of intrusive and metamorphic bedrock (bottom panels).

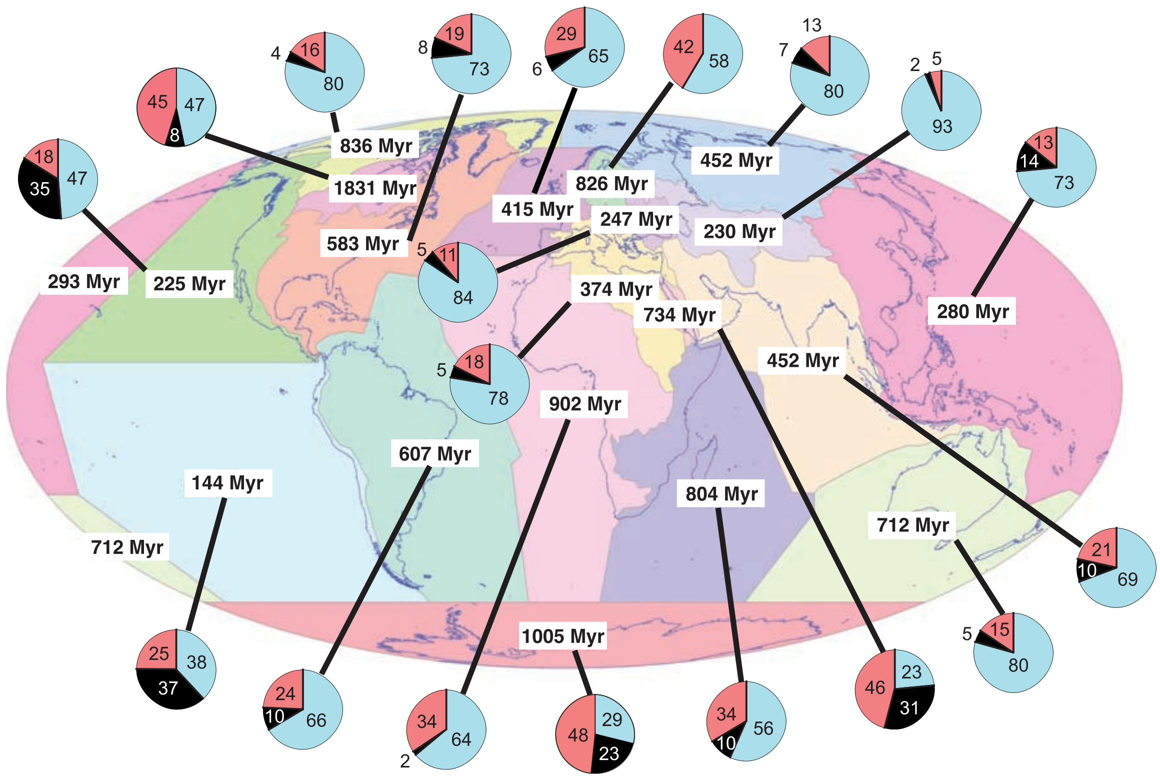

Figure 6. Average bedrock ages, weighted according to bedrock area assuming a uniform age distribution, and lithologic composition of 19 large-scale drainage regions [*Graham et al.*, 1999] are shown. Pie charts indicate relative abundance (numbers in % inside or outside the pie charts) of extrusive (black), sedimentary (blue), and endogenous (red) bedrock in each drainage region. Marine areas, though shown in the same colors as the respective continental drainage region, were not included in the quantitative analysis because higher-resolution estimates have been published for the age distribution of oceanic crust.

rocks shifts by 45 Myr from 246 to 201 Myr. Ages of volcanic rocks shift from 331 to 283 Myr, whereas average ages of endogenous rocks decrease from 1745 to 1375 Myr. This comparison demonstrates that the choice of age model, the choice of absolute age of the lower Archean age limit as well as the map resolution (i.e., time resolution) affect average ages. These issues must be considered when comparing results derived from maps with different resolutions.

5. Large-Scale Drainage Regions: Results and Discussion

[13] Data for the 19 large-scale drainage basins and internally drained regions, as delineated by *Graham et al.* [1999, 2000], are summarized in Table 2 (complete data are in auxiliary material Table S2). The table includes data on the total surface area of each drainage region, and the relative proportions of land, lake, ice and ocean. In addition, the table includes data on the bedrock area and relative proportions covered by sedimentary, extrusive and endogenous bedrock. Average ages and age uncertainties (1 SD) for major lithologic units are also given. The raw data are presented in auxiliary material Table S2. The lithologic makeup of these large drainage areas ranges from regions dominated by sedimentary bedrock (93.3% Caspian and Aral Seas; 84.4% Black Sea; 80.3% Russian Arctic) to regions with higher relative abundances of extrusive (37.3% West coast of South America; 35.0% West coast of North America, 30.9% Red Sea) and endogenous bedrock (48.4% Antarctica; 45.7% Red Sea; 45.3% Hudson Bay). The relative abundance of sedimentary bedrock varies from 23.4% (Red Sea) to 93.3% (Caspian and Aral Seas). The relative abundance of extrusive rocks ranges from 0% (Baltic Sea) to as much as 37.3% (West coast of South America), whereas the relative abundance of

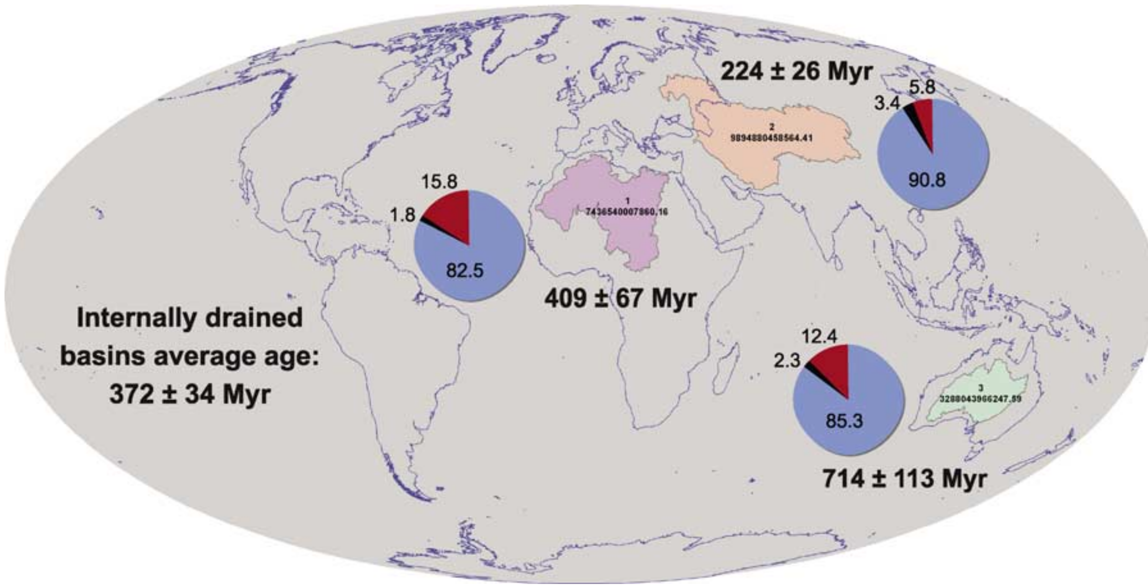

Figure 7. Large-scale internally drained basins, shown with gridcode number (1–3), surface area (m^2), average bedrock age with 1SD age uncertainty (uniform age distribution), and pie charts depicting the relative bedrock composition of each basin and area percentages. Blue, sedimentary bedrock; black, extrusive volcanic bedrock; red, endogenous bedrock. Note that the surface area values are those calculated on the basis of the 5-minute data. Small internally drained basins, such as the Salt Lake and Death Valley (U.S.), the Dead Sea (Palestine, Jordan), and Okavango Delta (Botswana) as well as endorheic basins in southern Argentina, are not shown.

endogenous rocks is as low as 4.8% (Caspian and Aral Seas) and as high as 48.4% (Antarctica).

[14] The age structure of these large-scale drainage regions varies considerably, reflecting the relative abundance of predominantly young sedimentary and extrusive bedrock versus old endogenous bedrock (see Figures 3–5). The average bedrock ages of the large-scale drainage regions, weighted according to bedrock area, varies by more than an order of magnitude from 144 ± 22 Myr (1 SD) for the west coast of South America to 1831 ± 132 Myr (1 SD) for the Hudson Bay (auxiliary material Table S2 and Figure 6). The geologic makeup and age structure reflects the predominant geotectonic setting in each of the 19 large-scale drainage regions. Regions dominated by convergent margins, particularly those involving oceanic and continental plates (e.g., west coasts of North and South America) are dominated by young bedrock with large proportions of extrusive rocks. Regions that are dominated by Precambrian shields are, in contrast, characterized by old bedrock (e.g., Hudson Bay, Baltic Sea) and generally have a higher proportion of endogenous bedrock.

[15] Average bedrock ages of three large-scale endorheic regions (see Table 2 and auxiliary material Table S3) vary from 224 ± 26 Myr (central Asia) to 714 ± 113 Myr (central Australia). The average age of all endorheic basins is about 200 Myr younger (372 ± 34 Myr) than the global average bedrock age (574 ± 65 Myr). This offset is caused by the predominance of sedimentary (87%), and limited exposure of endogenous (11%) bedrock in such basins (see Figure 7). Consequently, the average age of exorheic land area is ~35 Myr older than the global average bedrock age. Formation and destruction of internally drained basins during plate tectonic evolution of the Earth's crust is one mechanism affecting the average age of the bedrock that is hydrologically connected to the oceans.

6. Summary

[16] We show that the world bedrock data at a scale of 1:25,000,000 is sufficiently accurate for a quantitative assessment of global bedrock geology. The data can be used to investigate the regional variability of bedrock in large-scale drainage basins. We show that regional variations are considerable, both with respect to lithologic composition and age structure. At a statistically meaningful coverage of at least ~20 polygons per drainage area, the average spatial resolution of the world bedrock data (~13,000 km^2 $polygon^{-1}$) is sufficient for performing bedrock analyses of river drainage

basins larger than ~250,000 km^2. At this resolution the ~50 largest river basins [*Meybeck and Ragu*, 1996] can be investigated, and the makeup of their bedrock lithology and age structure compared with hydrochemical data [*Amiotte Suchet and Probst*, 1995]. Such an analysis may reveal interesting correlations between bedrock geology and chemical composition of continental runoff, thereby enhancing our understanding of linkages between temporal variations in the surface of Earth and the chemical composition of seawater.

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